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Art. IX.—*Phenomenal Colonization of Diatoms in Aqueducts.*

By A. D. HARDY.

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Abstract.

An algal infestation of aqueducts of the Melbourne and Metropolitan Board of Works supply occurred in 1941 and has, seasonally, recurred between cleansing operations. The algae were chiefly diatoms. In one of the channels which was affected for many miles, the diatomaceous growth appeared on the cement walls as an oyster-coloured, felt-like stratum and comprised about a dozen species of which a few were dominant. In parts the felt was composed exclusively of the diatom *Gomphonema oxycephalum* Cleve. var. *subacuta*, var. n.

The cause of this phenomenal colonization in a hitherto unaffected, 12-year old aqueduct has not been satisfactorily determined, but it is suggested that much carbon and ash entered the highland streams during the forest fires of 1939 and, with the silica resulting from the subsequent erosion, afforded an abundance of shell building material for the diatoms.

In the Spring of 1940 the open channels of the Melbourne and Metropolitan Board of Works Water Supply became infested with an abnormal growth of algae of which, especially in one channel, the greater part was almost wholly diatomaceous. The walls of the channel became covered with a felted stratum for miles; and this was replaced by new growth after cleaning operations by the Board's officials, or the natural peeling from the cement. The daily clearance of accumulations of masses involved labour diverted from other urgent work and on that account the growth was objectionable, but, otherwise, little inconvenience was caused, and no discomfort was experienced by consumers.

As the channels of the several aqueducts affected were those below their respective storage reservoirs, excepting one instance to which reference will be made, and not the inlet channels, a brief description of the four reservoirs is given.

The Reservoirs.

The water supply for the reticulation of Melbourne and suburbs is obtained from the forested southern slopes of the Dividing Range, where the average annual rainfall is between 50 and 60 inches. The reservoirs—Yan Yean, Maroondah, O'Shannassy, and Silvan—all receive water from tributaries of the Yarra River; but Yan Yean receives via Toorourrong reservoir a supplementary supply diverted from the north side of the range.

1. The Yan Yean system comprises (*a*) Yan Yean reservoir which has its local catchment on Silurian formation; (*b*) Toorourrong reservoir, which receives water directly from tributaries of the Plenty River; the catchment area being part granite and part Silurian; (*c*) the supplementary supply from the north side of Mt. Disappointment where tributaries of King Parrot Creek are tapped at Silver Creek weir, and Wallaby Creek dam. The water is then gravitated to a saddle in the range, and descends to Toorourrong by a series of cascades and the natural course of Jack's Creek. This diverted water is from granitic formation.

Yan Yean reservoir has a capacity of 6,250 million gallons and an altitude of about 600 feet. A monthly collection of algae from this reservoir by the author in 1905-6 has been described by G. S. West (1).

2. Maroondah reservoir has an altitude of approximately 460 feet and has a dacite catchment area of about 40,000 acres. Its storage capacity is approximately 6,274 million gallons.

3. O'Shannassy reservoir, with a capacity of 930 million gallons, is at an altitude of about 1,200 feet, and collects water from the watershed of the Ligar River (originally "Bellell"). The greater part of this 32,000 acres is dacite. At the southern (lower) end of the catchment there is a small area of Silurian rocks. The highest point of the watershed is Mt. Arnold (4,300 feet). A few miles below the dam the O'Shannassy water is supplemented by water conveyed along an open channel and a siphon from McVeigh's where the Upper Yarra catchment is a Silurian area. Unlike Yan Yean and Toorourrong, but resembling Maroondah, the O'Shannassy reservoir is bounded by steep slopes to the water's edge, and shows a comparative paucity of phytoplankton and an almost complete absence of littoral host plants for the harbourage of diatoms and other algae.

This water flows in open channels and siphons about 22 miles to Silvan reservoir, with the addition of some from Corranderrk Creek in the Maroondah area.

4. Silvan reservoir is held by a dam 2,100 feet long and 140 feet high at an altitude of about 800 feet in the Dandenong Range. The local catchment is a dacite area of about 1,200 acres. The reservoir stores from this, and the borrowed O'Shannassy and Maroondah quotas, some 8,800 million gallons. The highest part of the local watershed is less than 2,000 feet. From the north end of Silvan, where the inlet and outlet are only about $\frac{1}{2}$ mile apart, the mixed water is conducted by open channel and siphon about 5 miles to the Olinda service reservoir, at altitude 670 feet, and thence by underground pipes to various reservoirs and the reticulation.

The Aqueducts.

With the exception of siphons, the Board's aqueducts are cement-faced channels, varying in cross-section both in shape and area, but a brief description of the O'Shannassy-Silvan-Olinda channel at a point above the Silvan Inlet will serve, as the variations are immaterial in the present connexion. The cemented walls slope up from a 9 feet wide bottom at an angle of 45°, providing for a water depth of about 4 feet and a freeboard of 9 inches as at full flow on one date of inspection; the flow being then at the rate of 3·1 feet per sec. The channel is provided with wooden gratings in which the openings are from about ½ in.–1 in. wide, set at an angle of about 30° from the horizontal, for the arrest of twigs, leaves and other forest debris, at siphon entrances, &c. At the pipe-head reservoir a further arrest is made on copper screens, the wires of which are about ·5 mm. apart.

The rate of flow, mentioned above, was sufficient to float innumerable fugitive masses of the algal felt, usually below the surface, to the gratings, where the larger masses were held. Others passed through, and on to Silvan reservoir where some sank, a few were caught on twigs, &c., and the remainder, passing through the north end of this reservoir, entered the Silvan-Olinda section, where, with the exception of very small fragments, they accumulated 5 miles down on the wire screen. A few fragments passed into the reticulation and clogged the meters.

The quality of the water which passed over miles of the felt was unaffected. The exclusively diatomaceous material was odourless and tasteless, tough and "gritty" between the teeth. Even when a mass was crammed into a jar, with only sufficient water to cover it, there was no objectionable odour after weeks or even months of stagnation. If drained and enclosed in a partially air-tight vessel, however, the material became maladorous within 24 hours. Material with considerable inclusions of green algae soon putrified in similar confinement. When dried, this oyster-coloured diatomaceous felt lost about 85 per cent. of its weight and assumed a greyish-green colour (due to loss of the camouflaging diatomin revealing the chlorophyll).

The Algae of the Channels.

In all the channels there are normally, between times of cleaning operations and especially in spring and early summer, species of *Spirogyra, Zygnema, Mougeotia, Ulothrix*, and, but more noticeable in that of Maroondah than the others, *Oedogonium* spp. The Zygnemaceae have not been collected in fruiting condition, cleaning of the channels anticipating the spore formation. The bright green streamers in the current attain a length of 12 inches or

more, usually in a zone with limits approximately 6 inches and 24 inches below the surface. These streamers of filamentous algae strain from the water many small chlorophytes, diatoms, flagellates, &c. Myxophytes also abound in places, appearing as dark-green velvet-like patches extending from about 9 inches below the surface to some inches above, the aerial parts being revivified by increased volume of water. In these masses small animals find shelter: *Nais, Anguillula,* Rotifers, and Entomostraca. The rich microflora of the Yan Yean is represented in its channel by inclusion of some of its permanent constituents, including at times plankton species which are not, or rarely, in the phytoplankton of Maroondah, O'Shannassy or Silvan.

Previous Abnormal Increases of Algae.

The first superabundance of any species was that of an unknown desmid, about 40 years ago. This plant (*Micrasterias hardyi,* G. S. West) remained in excess during some weeks, then slowly diminished, and, though permanently in the plankton, has not abnormally increased since.

In 1929, soon after the infestation of the Hume reservoir on the Murray River, by *Anaboena circinalis* Rabenh., the same species appeared in the Yan Yean, and so rapidly increased that the surface water appeared pea-green, and depth samples showed a vertical distribution. After some weeks' duration, its departure was hastened by chemical treatment, following which, however, a diatom, *Melosira granulata* Ralfs, became superabundant and, after the precipitation of the Anaboena, remained for some weeks, prolonging the turbidity of the water with a milky cloudiness. This diatom diminished in numbers, but, before it became normal, another diatom, *Rhizosolenia morsa* W. and G. S. West, supervened. This species further prolonged the turbidity during some weeks and then slowly diminished. These two diatoms, though permanent constituents of the Yan Yean plankton, have rarely appeared in the channel and then only as a few scattered individuals in an abundance of other algae. That the channel was not troubled with these during their abnormal increase in the reservoir was at least partly due to the Board regulating the flow from the variable inlet valves of the outlet tower at an early date, and reserving the water during the peak period of increase.

In Maroondah in 1928, two diatoms, *Cyclotella Meneghiniana* Kütz and *C. stelligera* Cleve and Grun, increased to such an extent that chemical treatment was contemplated, but the growth naturally diminished. The only other abnormal development of algae in this reservoir was the over-production of a desmid —*Staurastrum paradoxum* Meyen, var. *longpipes,* Nordst. This was subdued with an algicide.

In the O'Shannassy there has been from its early years a disproportion of animal forms up to the appearance of crustacea and a few chlorophytes in recent years. The protozoa *Lacinularia elliptica* and *Stentor igneus* increased to the extent of macroscopic visibility, the former like innumerable sago grains, the latter like myriads of poppy seeds, and caused turbidity in the normally crystal-clear water, but with no ill effect. Diatoms were very rare in the plankton.

At no time has there been an increase of diatoms in this reservoir or its channel until the occurrence under notice. The diatoms of the channel have been chiefly those of the Ligar River, at the inlet. In Silvan reservoir, also, where there is a meagre phytoplankton, no abnormal increase of diatoms or other algae has been observed, the only untoward occurrence in its history being a plague of entomostraca (chiefly Cladocera) and a recent marginal growth of *Potamogeton ochreatus* Raoul, which attained a height of over 20 feet, in dense formation, but too recently to be a suitable home for epiphytic diatoms.

The Infestation of the O'Shannassy Channel.

The felting of the sloping walls of the O'Shannassy-Silvan-Olinda aqueduct channel was extensive and almost continuous from the lower terminus to at least the Cement Creek crossing (where arrested accumulations were removed by the barrow load) and beyond, in diminishing quantity, but not beyond the Upper Yarra siphon which introduces water from the Silurian, a circumstance which at first seemed significant. But the felt also occurred sparsely in the Maroondah channel, in water from an exclusively dacite area.

The O'Shannassy felt is distinguished from that of the Maroondah by the predominating and, in parts, exclusive presence of a new variety of the diatom *Gomphonema oxycephalum* Cleve (8), which morphologically and in habit resembles *G. intricatum* Kütz.

Suggestion as to Cause of the Colonization.

The foregoing description of the watersheds and channels does not indicate any topographical or geological factor as a cause of the origin of this phenomenal colonization. The only unusual meteorological occurrence which might have significance was the terrific heat wave, in the summer of 1938-9, during which temperatures in Victoria rose to 117° F., in the shade, and led to the devastating forest fires in that January. Much ash and carbon entered the forest streams, and later, during 1939-40, the soil erosion which followed the destruction of the foliage in many areas must have added a superabundance of silica to the water in those regions and so provided ample material for the construction of diatom frustules, which, according to one analysis (2)

of diatomite, amount to 40,000,000 to a cubic inch, and, to another, approx. 80 per cent. silica (3). This explanation would apply to all the channels, but does not account for the predominance in one channel of a species of *Gomphonema* which is found sparsely in the sources of all; nor the adoption of the cemented walls as a substratum. However, William Smith (1857) (3) records for *Gomphonema intricatum* Kütz " forming a velvet-like stratum on the surface of a chalk cliff . . . Sussex, August, 1890."

During a peak period a 24 hours' accumulation at the lowest screen was found to weigh approximately 2,000 pounds or 300 dry weight (avoir.). This did not include much which was removed from local screens and gratings at several points higher up; e.g., two barrow loads were removed from the highest, at the Cement Creek crossing. Thus the transportation by stream flow amounted to many tons wet weight in a season; a fresh felt forming after the natural peeling or artificial removal of the old stratum.

In the foregoing account two methods of diatomite formation are suggested—(1) The generally recognized deposition of diatoms *in situ*, in calm or nearly calm water, as indicated by the sedimentation by *Melosira granulata* and *Rhizosolenia morsa* after abnormal increase in the Yan Yean reservoir; (2) the *ex situ* deposition after transportation over considerable distances varying with stream flow, and limited only by obstacles encountered. In the latter case unimpeded fragments might reach the sea and with the disintegration of the gelatinous matrix free the frustules of the dead diatoms to be carried further afield and appear in an apparently remote marine habitat. Rare specimens of fresh water species recorded for South Polar region (4) might thus be accounted for.

But because the extensive colonization described did not occur in the natural water courses, for lack of suitable substratum or other cause, the occurrence in the channels may be attributable to the artificial conditions. If so, it seems significant that in addition to an abundant food supply, the silica resulting from the bush fires and silt from post-fire erosion combined with the alkaline ingredient contained in the channel cement provided the necessary material for diatom-shell construction.

It is noteworthy that while the filamentous chlorophytes retained their accustomed hold on the other channels, where the diatoms while prolific were not dominant, the amount of green algae in the O'Shannassy channel was for the greater part negligible. At the same time metropolitan horse-troughs which, when constructed

with iron accommodated green algae, have been devoid of algae excepting a thin film comprising a few species and diatoms, since the construction has been of concrete and cement.

Notes on Some of the Species.

Gomphonema oxyccphalum, Cleve, var. *subacuta,* n. var. The type, described and figured by Cleve (8) has the upper part of the valve within an angle, which measures 25°. In the variety the margins of the upper part of the valve are often slightly concave and there is occasionally a slight constriction at the subacute apex. The proportions of length and breadth also vary considerably, e.g., 34 μ by 6 μ and 24 μ by 5 μ. The striae are more coarsely beaded; the hyaline space varies from narrow lanceolar to almost linear. The single stigma when present is not conspicuous. In general appearance the valve resembles *G. intricatum,* Kütz. In girdle view the new valves diverge about 10°.

Melosira granulata, Ralfs. This species is a constituent of the Yan Yean plankton, and has not been collected from O'Shannassy or Maroondah. It is normally rare in the Yan Yean channel and very rare in the felt. It increased abnormally in the Yan Yean in 1929. It is the sole species in some diatomites, viz., near Fraser Lake, Vancouver Id. B.C. (5), and Coonabarabran, New South Wales (6); it closely resembles, if not identical with, "*Melosira granulata,* Ehrenb." referred to by Card and Dun (6) as occurring in some Victorian diatomites. It is the almost exclusive species in some Canadian diatomites (5).

Hantzschia amphioxys (Ehrenb.) Grun. is in the highland streams and many lakes and pools in Victoria, and all the reservoirs and channels. It formed about the thousandth part (numerically) of the "Red Rain" (7) dust particles, from Central Australia, collected by me from the snow at Mt. Buffalo Chalet (4,500 feet) on July, 1935. By rough estimate about 30 lb. of the frustules of this species fell into the Yan Yean reservoir, after a dust storm of similar nature, in December, 1938. Empty frustules of any species occurring rarely in the channels without accompanying living representatives are therefore not listed (cf. 4).

Synedra ulna (Nitzch) Ehrenb., *S. radians,* G. S. West, *Tabellaria flocculosa* (Roth.) Kütz., *Eunotia crispula,* G. S. West, *Navicula viridis,* Kütz., *N. radiosa,* Kütz., *N. amphisbocna* Bory., *N. bicapitata,* Lagerst., var., *Cocconeis placentula,* Ehrenb., *Cyclotella Meneghiniana,* Kütz., *C. stelligera,* Cleve and Grun., and *Cocconema gracile,* Ehrenb. were the most numerous species in the "mixed" parts of the felt.

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